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Potassium chloride fertilization of potatoes: nutrient uptake rate and tuber yield of cultivars Ágata and Atlantic

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ABSTRACT

Potassium (K) is the nutrient taken up in the greatest quantity by the potato plant. Obtaining information about the relationship between tuber yield and K application rate allows improvements in fertilizer use efficiency. We aimed to evaluate the variation in potassium fertilizer doses in uptake rate of other nutrients and in potato tuber yield. The experiments were carried out in Unaí-MG testing cultivars Ágata and Atlantic and in Mucugê-BA evaluating cultivar Ágata. The experimental design used was randomized blocks. We studied the rates of 0; 70; 110; 220, and 450 kg ha^{-1} K_2O. The increase in K rate reduced the levels of S, Ca, Mg and B in Atlantic-Unaí, Ca, Mg, Zn and B in Ágata-Unaí and S, Fe and B in Ágata-Mucugê. The cultivar Atlantic-Unaí did not respond to the increase of potassium fertilizer dose, with a total of 32.3 to 37 t ha^{-1}. Cultivars Ágata-Unaí and Ágata-Mucugê responded to rates estimated at 225 and 166 kg ha^{-1} K_2O with the highest productivities of 53.9 and 56.2 t ha^{-1}, respectively.

Keywords: *Solanum tuberosum***,** mineral fertilization, plant nutrition.

RESUMO

Adubação em batata com cloreto de potássio: taxa de absorção de nutrientes e produtividade de tubérculos de Ágata e Atlantic

O potássio (K) é o nutriente mais absorvido pela batateira. Conhecer a relação entre a produção e a taxa de K aplicada permite melhorar o uso de fertilizantes. Objetivou-se avaliar a variação de doses de fertilizante potássico na taxa de absorção de outros nutrientes e na produtividade de tubérculos de batata. Os experimentos foram conduzidos em Unaí-MG com as cultivares Ágata e Atlantic e em Mucugê-BA com Ágata. O delineamento utilizado foi de blocos ao acaso. Foram avaliadas as doses 0; 70; 110; 220 e 450 kg ha^{-1} de K_2O. O aumento da dose de K reduziu os teores de S, Ca, Mg e B em Atlantic-Unaí, Ca, Mg, Zn e B em Ágata-Unaí e S, Fe e B em Ágata-Mucugê. A cultivar Atlantic-Unaí não respondeu ao aumento da adubação potássica, com produtividade total entre 32,3 e 37 t ha^{-1}. A cultivar Ágata-Unaí e Ágata-Mucugê responderam até as doses estimadas de 225 e 166 kg ha^{-1} de K_2O com produtividades máximas de 53,9 e 56,2 t ha^{-1}, respectivamente.

Palavras-chave: *Solanum tuberosum*, fertilização mineral, nutrição de plantas.

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Potatoes are highly nutrient-demanding plants, and potassium (K) is the nutrient which is taken up in the greatest quantity (Job *et al.*, 2019). Potassium increases plant height and crop vigor, playing an important role in translocating carbohydrates from the leaves to roots (Jasim *et al.*, 2013). Potassium-deficient soil can significantly cause damage to potato crop (Pervez *et al.*, 2013).

Potato cultivars behave differently in relation to potassium demand, according to its yield potential and number of tubers. Therefore, besides having reliable information on soil components, the nutrient dose should meet the needs of each cultivar (Bansal & Trehan, 2011).

In Brazil, the lack of studies on the nutrient-use efficiency in crops, in different soils and states, makes the producers use fertilization in amounts greater than required: it increases crop production costs and reduces the fertilizer-use efficiency (Fernandes & Soratto, 2013).

Thus, studies on the main cultivars used in Brazil should be stimulated, aiming to provide information on the dynamics of nutrients. The results help prevent producers to follow standardized recommendations and luxury consumption of K by the potato crop, as well as optimize productivity and fertilizer use in agriculture (Silva & Fontes, 2016).

In literature, potato crop responded to doses from 150 to 400 kg ha^{-1} K_2O, considering the highest doses related to low availability in soil, as well as the highest clay contents (Silva & Fontes, 2016; Zelelew *et al.,* 2016). According to Zörb *et al.* (2014), prioritizing K fertilization is necessary to overcome soil fertility decline and improve productivity, guaranteeing food safety. Relationship between productivity and soil exchangeable K content allows to determine critical K value, below or above which different K fertilization strategies can be adopted (Sandaña *et al.*, 2020), so that they maximize resource savings and ensure greater profitability through satisfactory and quality production. Thus, the aim of this study was to evaluate the influence of potassium chloride doses on nutrient uptake rate and on the tuber yield of potato cultivars Ágata and Atlantic.

MATERIAL AND METHODS

Location and installation

The experiments were installed in potato-producing rural properties in the municipality of Unaí-MG and Mucugê-BA, using cultivars Ágata and Atlantic, and cultivar Ágata, respectively.

In Unaí-MG (16°21'27"S, 46°54'22"W, 640 m altitude), Ágata and Atlantic were grown from May to August and from June to September, 2014, in a clay-texture soil, classified as typic distrophic Red Latosol. The local climate is Awi according to Köppen. Total rainfall of 50 and 57 mm from May to August and June to September, respectively. Maximum and minimum temperature from May to August ranged from 29 to 37°C and 9 to 14°C, respectively, and from June to September, 2014, from 29 to 40°C and 9 to 17°C, respectively. Relative humidity ranged from 51 to 68% and 52 to 64% from May to August and from June to September, respectively.

In Mucugê-BA (13°00'19"S, 41°22'15"W, 986 m altitude), the growing season was from September to December, 2014. The local climate is Cfb according to Köppen, maximum and minimum temperature ranged from 25 to 29°C and 12 to 16°C, respectively. Relative humidity ranged from 62 to 80% and total rainfall was 350 mm. The soil in the experimental area is medium texture and classified as Red-Yellow Latosol (Embrapa, 2017).

Soil chemical analysis of this area was performed before planting, in the 0-20 cm layer, according to the method described by Embrapa (2017). Chemical characterization of the soils was: Ágata-Mucugê: pH (H_2O) = 5.7; P (Mehlich) = 11.7 mg dm^{-3}; K = 84 mg dm^{-3}; Ca = 1.3 $cmol_c$ dm^{-3}; Mg = 0.4 $cmol_c$ dm^{-3}; H+Al = 1.8 $cmol_c$ dm^{-3}; CTC = 3.7 $cmol_c$ dm^{-3} and V = 51.9%; Ágata-Unaí: pH (H_2O) = 5.2; P (Mehlich) = 14.5 mg dm^{-3}; K = 84.4 mg dm^{-3}; Ca = 2.9 $cmol_c$ dm^{-3}; Mg = 1.1 $cmol_c$ dm^{-3}; H+Al = 3.5 $cmol_c$ dm^{-3}; CTC = 7.7 $cmol_c$ dm^{-3} and V = 54.6% and Atlantic-Unaí: pH (H_2O) = 5.3; P (Mehlich) = 17 mg dm^{-3}; K = 89 mg dm^{-3}; Ca = 3.2 $cmol_c$ dm^{-3}; Mg = 0.9 $cmol_c$ dm^{-3}; H+Al = 3.6 $cmol_c$ dm^{-3}; CTC = 7.9 $cmol_c$ dm^{-3} and V = 54.4%.

For each cultivar and location, we evaluated the effect of potassium dose (0, 70, 110, 220 and 450 kg ha^{-1} K_2O). The standard dose of N and P fixed in 120 kg ha^{-1} N and 480 kg ha^{-1} P_2O_5, followed the recommendations of Soil Fertility Commission of Minas Gerais (Comissão de Fertilidade dos Solos de Minas Gerais) (CFSEMG, 1999). Sources of N, P and K used were urea, triple superphosphate and potassium chloride, respectively. At planting, the following micronutrients were applied: 2.2 kg ha^{-1} boron and copper and 5.4 kg ha^{-1} manganese and zinc in Unaí-MG and 2.5 kg ha^{-1} boron, copper and zinc and 5 kg ha^{-1} manganese in Mucugê-BA.

Experimental design

The experimental arrangement was in randomized blocks, with four replicates. Each plot consisted of six 6-m long rows, spaced 0.8 m between rows and 0.3 m between plants, totalizing a total area of 28.8 m^2 per plot. Evaluations were done in two central rows, in the useful area of the plot, totalizing 8 m^2; the other plants formed the plot border.

Installation and conduction of the experiment

Maize had previously been grown in the experimental areas. Three months before planting, liming was performed. We used dolomitic limestone (PRNT: 90%) at a dose of 1 and 0.9 t ha^{-1} in Ágata-Unaí and Atlantic-Unaí, respectively, and 0.6 t ha^{-1} in Ágata-Mucugê. After preparing, plowing and harrowing the soil, furrows were opened. Nutrient doses were distributed into planting furrows manually, being incorporated using a hoe. In the three experiments, of the total N and K applied, 60% were distributed at planting, and the other 40% in mulching, 27 days after planting (DAP) when hilling up was performed. The total dose of P was distributed at planting.

In these experiments, potato plants were grown under center-pivot irrigation, supplied with sufficient water for the full development of the crop (500 – 550 mm) throughout the cultivation period. Generally, a 6-mm water depth was applied in both areas, every 2 days, from emergence to hilling up, 10 mm during vegetative development and 12 mm, every 3 days, in stolonization and tuberization phases.

According to monitoring of pests, diseases and weeds, products registered for potato cultivation were applied, when necessary, following the recommended doses (Lopes *et al.*, 2016; Nava & Diez-Rodríguez, 2016; Silva, 2016).

Evaluated traits

Macro and micronutrient contents in leaves

In each place and cultivar, at 35 days after planting (DAP), 20 expanded leaves from the third fully developed trefoil of each plot were collected (CFSEMG, 1999). The leaves were kept in paper bags and sent to Safrar agricultural laboratory (laboratory of agricultural analyses) in order to quantify the nutrients.

The sampled leaves were washed according to the methodology of Bataglia *et al.* (1983). In order to quantify dry mass, fresh vegetables were placed in an oven with forced air circulation at 65°C. After that, the leaves were ground and the macronutrient contents in leaves were determined: nitrogen, phosphorus, potassium, calcium, magnesium, sulfur and the micronutrients: boron, copper, iron, manganese and zinc (Embrapa, 1997).

Productivity and quality of tubers

At 90 DAP, desiccation in experiments with Agata cultivar was carried out using 2.5 L ha^{-1} herbicide diquat (500 g ia ha^{-1}). In the experiment with Atlantic, no desiccation was done. At the end of the experiments (112 and 115 DAP for Ágata-Unaí and Atlantic-Unaí and 106 DAP for Ágata-Mucugê), the tubers in the useful area of the plots were manually collected (discarding 0.5 m of the end of each row), classified and weighed using an electronic scale. The obtained values were transformed in t ha^{-1}.

Classification was carried out according to the Ministerial Order No. 69, of February 23, 1995, by the Ministry of Agriculture, Livestock and Food Supply (MAPA); the tubers were classified according to the diameter: special (>45 mm), commercial (greater than or equal to 33 mm and less than 45 mm) and non-standard (less than 33 mm). The sum of the classifications constituted the total productivity.

Statistical analysis

Obtained data were initially tested in order to estimate the normality of residuals (Shapiro-Wilk test), homogeneity between variances (Levene test) and block additivity using the SPSS software (SPSS, 2008). The averages of the treatments were submitted to variance analysis (F test), using SISVAR software and then submitted to polynomial regression analysis (first and second degrees) being selected the equation with the highest coefficient of determination (statistically significant) (Ferreira, 2014).

To analyze the main components (PCA), we used N, P, K, S, Ca, Mg, Cu, Fe, Mn, Zn, B in the leaves and total productivity. New axes, eigenvectors (new variables) called main components (PC), were generated by linear combinations of original variables built using eigenvalues of a covariance matrix (Piovesan *et al*., 2008; Hair Junior *et al*., 2009). In order to obtain a more simple form and a more parsimonious model, we used the Kaiser criterion (2002) with eigenvectors above the unit. Analyses were performed using R programming language.

RESULTS AND DISCUSSION

Macro and micronutrient contents in leaves

No effect of K doses on leaf N and P contents in Ágata-Unaí and Ágata-Mucugê was noticed. Contents ranged from 50.9 to 52.0 and 1.6 to 3.5 in Ágata-Unaí and 42.7 to 44.5 and 2.7 to 3.2 g kg^{-1} of dry mass (MS) in Ágata-Mucugê. K doses above 228.3 and 230.0 kg ha^{-1} K_2O reduced N and P contents in Atlantic-Unaí, respectively. All N and P contents were within a suitable range for potato crop (Lorenzi *et al.*, 1997), except when K_2O doses up to 70.0 kg ha^{-1} were used, making P content be below the suitable level (Table 1). All the values for P found in this study were inferior to the recommended by Pauletti & Motta (2019).

Leaf K content increased linearly with K dose in Atlantic-Unaí. Doses above 292 and 232 kg ha^{-1} K_2O reduced K content in Ágata-Unaí and Ágata-Mucugê, respectively. Doses up to 70 kg ha^{-1} K_2O were lower to the suitable in Atlantic-Unaí and Ágata-Mucugê, within the range proposed by Lorenzi *et al.* (1997) (40 – 65 g kg^{-1} MS) and Pauletti & Motta (2019) (64 g kg^{-1} MS); the other doses of all experiments were considered suitable (Table 1).

The increase of K doses decreased linearly the Ca and Mg contents in Ágata-Unaí. Doses above 87.5 and 156.7 kg ha^{-1} K_2O decreased these nutrient contents in leaves in Ágata-Mucugê. In Atlantic-Unaí, doses of K_2O did not influence contents of Ca and Mg, which ranged from 15 to 19.7 and 6.6 to 8.9 g kg^{-1} MS, respectively (Table 1). All values found in the three experiments were suitable for Ca and higher to suitable for Mg, considering all the suitable content values suggested by Lorenzi *et al.* (1997) and Pauletti & Motta (2019).

S contents decreased linearly with an increase of K dose, in Atlantic-Unaí and Ágata-Mucugê, not being influenced by the dose range in Ágata-Unaí, which presented 1.2 to 1.3 g kg^{-1} MS (Table 1). All S contents in the three experiments were lower to the ones considered suitable by Lorenzi *et al.* (1997) and Pauletti & Motta (2019).

Fernandes *et al.* (2011) also observed doses lower to the ones considered suitable for some potato cultivars. Thus, we highlight the importance of establishing recommendation fertilization tables for S for potato cultivars in different Brazilian states.

All nutrients must be in balance and in suitable amounts required by the crop, considering that high K doses do not guarantee adequate productivities, since K accumulation tends to decrease the uptake of other nutrients, such as Ca, Mg, Fe, S and P and consequently interfere in metabolic processes of the plant. In this case, we recommend the use of foliar application (leaf spray) in order to create favorable conditions for good crop growth (Zörb *et al.*, 2014).

Zn contents were not influenced by K doses, ranging from 65.8 to 76; 34.7 to 39.5 and 48.7 to 51 mg kg^{-1} MS in Atlantic-Unaí, Ágata-Unaí and Ágata-Mucugê, respectively (Table 1). The contents were suitable (Lorenzi *et al.*, 1997; Pauletti & Motta, 2019) for Atlantic-Unaí and Ágata-Mucugê and low comparing to the suitable value for cultivar Ágata-Unaí.

Cu contents increased up to dose of 376.8 and 287 kg ha^{-1} K_2O in Ágata-Unaí and Ágata-Mucugê, respectively. The increase of K doses did not influence Cu content in Atlantic-Unaí, ranging from 49.9 to 73.5 mg kg^{-1} MS (Table 1). All contents were higher than the suitable doses recommended by Lorenzi *et al.* (1997) and Pauletti & Motta (2019).

Increasing K doses reduced linearly B contents in all experiments (Table 1). In Ágata-Unaí and Ágata-Mucugê, B contents were suitable for potato crop. In Atlantic-Unaí, the contents were lower when compared to suitable dosage, according to Lorenzi *et al.* (1997) and Pauletti & Motta (2019) recommendations.

Increase of K dose reduced leaf Fe contents in Ágata-Mucugê, increased the contents in Atlantic-Unaí up to the dose of 418.0 kg ha^{-1} K_2O and did not interfere in contents in Ágata-Unaí, which ranged from 211.0 to 237.6 mg kg^{-1} MS (Table 1). In all the experiments, the contents were higher than the suitable ones according to Lorenzi *et al.* (1997) and Pauletti & Motta (2019).

Leaf contents of Ca, Mg, Cu and Zn in Atlantic-Unaí, Mg and B content in Ágata-Unaí and Ca and Mg in Ágata-Mucugê were higher than the ones found by Fernandes *et al.* (2011) and Soratto *et al.* (2011), and the other macro and micronutrients were inferior to the ones found by the cited authors, in all the experiments (Table 1). The differences between the growing regions, the applied dose and general management of the crop were also responsible for changing the response of the cultivars and nutrient uptake among the experiments.

Analyzing the low limits of the ranges of nutrient values considered suitable for Lorenzi *et al.* (1997) and the contents found in populations with no potassium fertilization, the authors observed that K, S and B contents were 16.8; 38.8 and 16.5% lower than the ones considered suitable in Atlantic-Unaí; contents of S and Zn were 50.0 and 12.0% lower than the ones considered suitable in Ágata-Unaí and contents of K and S were 3.4 and 36% lower than the ones considered suitable in Ágata-Mucugê (Table 1).

In short, the increase of K dose decreased the contents of S, Ca, Mg and B in Atlantic-Unaí, Ca, Mg, Zn and B in Ágata-Unaí and S, Fe and B in Ágata-Mucugê.

Tuber productivity

Cultivar Atlantic-Unaí did not show any significance by F test for the special class productivity. Cultivar Ágata in both locations adjusted to quadratic polynominal model for special class. The maximum doses estimated in Ágata-Unaí and Ágata-Mucugê were 235.0 and 184.0 kg ha^{-1} K_2O, respectively, for productivity of 41.0 and 47.0 t ha^{-1} of tubers of special class (Figure 1A). The productivity of Atlantic ranged from 30.0 to 34.0 t ha^{-1}.

Soil constituents, source material and degree of weathering substantially reflect the effect of clay minerals on the retention or release of K (Zörb *et al.*, 2014). The difference between

Table 1. Macro and micronutrient contents in potato cultivar Atlantic and Ágata cultivated in Unaí-MG and Ágata cultivated in Mucugê-BA under potassium fertilization levels. Uberlândia, UFU, 2014.

Macronutrient	Cultivar and location	Equation	R2	Xmax (kg ha^{-1})	Ymax (g kg^{-1})	Suitable range (Lorenzi *et al.*, 1997)
	Atlantic Unaí	y = -0.00006x2 + 0.0274x + 43.965	40.52	228.33	47.09	
N	Ágata Unaí	--	-	-	-	40 – 50
	Ágata Mucugê	--	-	-	-	
	Atlantic Unaí	--	-	-	-	
P	Ágata Unaí	--	-	-	-	2.5 – 5
	Ágata Mucugê	y = -0.00001x2 + 0.0046x + 3.6415	66.86	230.00	4.17	
	Atlantic Unaí	y = 0.0167x + 32.883	86.93	450.00	40.39	
K	Ágata Unaí	y = -0.00005x2 + 0.0292x + 40.543	91.86	292.00	44.81	40 – 65
	Ágata Mucugê	y = -0.00006x2 + 0.0279x + 38.513	86.35	232.50	41.76	
	Atlantic Unaí	--	-	-	-	
Ca	Ágata Unaí	y = -0.005x + 15.933	51.46	450.00	13.68	10 – 20
	Ágata Mucugê	y = -0.00004x2 + 0.007x + 20.842	67.97	87.50	21.15	
	Atlantic Unaí	--	-	-	-	
Mg	Ágata Unaí	y = -0.0035x + 8.0991	74.93	450.00	6.52	3.5 – 5
	Ágata Mucugê	y = -0.00003x2 + 0.0094x + 6.833	90.69	156.67	7.57	
	Atlantic Unaí	y = -0.0006x + 1.5317	53.66	450.00	1.26	
S	Ágata Unaí	--	-	-	-	2.5 – 5
	Ágata Mucugê	y = -0.0005x + 1.6217	90.77	450.00	1.39	
Micronutrient					**(mg kg^{-1})**	
	Atlantic Unaí	--	-	-	-	
Cu	Ágata Unaí	y = -0.00008x2 + 0.0603x + 23.135	68.20	376.88	34.50	7 – 20
	Ágata Mucugê	y = -0.00005x2 + 0.0287x + 17.235	58.24	287.00	21.35	
	Atlantic Unaí	y = -0.0008x2 + 0.6693x + 214.72	87.98	418.31	354.71	
Fe	Ágata Unaí	--	-	-	-	50 – 100
	Ágata Mucugê	y = -0.0741x + 216.31	48.66	450.00	182.96	
	Atlantic Unaí	y = 0.0515x + 51.721	98.35	450.00	74.89	
Mn	Ágata Unaí	y = -0.0008x2 + 0.1651x + 103.04	82.53	103.19	111.56	30 – 250
	Ágata Mucugê	--	-	-	-	
	Atlantic Unaí	y = -0.0152x + 19.773	73.56	450.00	12.93	
B	Ágata Unaí	y = -0.0354x + 56.94	86.89	450.00	41.01	25 – 50
	Ágata Mucugê	y = -0.0351x + 54.45	68.91	450.00	38.65	

--not significant based on Tukey test, p<0.05.

K doses in Ágata-Unaí and Ágata-Mucugê may be related to soil texture. Clay-texture soils in Unaí-MG may have favored nutrient retention to soil colloids, justifying the greater response to potassium fertilization, 21.5% higher comparing with the maximum amount estimated in Mucugê-BA.

The high yield rates of tubers in special class, where no K application was done (33.0 to 41.0 t ha^{-1}), are related to good agricultural practices in these areas (pest and disease monitoring and pesticide applications at appropriate times).

Cardoso *et al.* (2007), Sing & Lal (2012), Silva & Fontes (2016) also observed positive response with K application in production of large and medium tubers.

The authors observed that the cultivars showed maximum yield with different K doses. The type of the soil and climate of each region were determinant when comparing the same cultivar. Therefore, criteria for recommendation considering the extraction rate of each cultivar and the growing region, according to physical and chemical characteristics, as well as monitoring the fertilization effects, improve the fertilizer use efficiency, provide higher accuracy in predicting dose and keep nutrients within suitable ranges (Qiu *et al.*, 2014; Zörb *et al.*, 2014; Fernandes *et al.*, 2016).

As for the commercial class, Atlantic-Unaí showed productivity from 1.6 to 2.4 t ha^{-1}, Ágata-Unaí responded positively up to dose of 140 kg ha^{-1}

Table 2. Average of macro and micronutrient contents in potato cultivar Atlantic and Ágata cultivated in Unaí-MG (groups 1 and 2, respectively) and Ágata cultivated in Mucugê-BA (Group 3) under potassium fertilization. Uberlândia, UFU, 2014.

Variables	Atlantic-Unaí (group 1)	Ágata-Unaí (group 2)	Ágata-Mucugê (group 3)
N*	45.7	51.5	43.4
P	2.8	3.0	3.9
K	35.3	42.9	40.1
S	1.4	1.3	1.5
Ca	17.4	15.2	19.9
Mg	9.7	7.5	6.9
Cu	77.2	29.2	19.3
Fe	284.2	229.2	204.0
Mn	59.6	105.8	234.3
Zn	77.3	36.6	49.1
B	17.4	51.1	48.6
Productivity	32.9	39.0	41.4

* N, P, K, Ca, Mg and S in g kg^{-1}; Cu, Fe, Mn, Zn and B in mg kg^{-1}; productivity in t ha^{-1}.

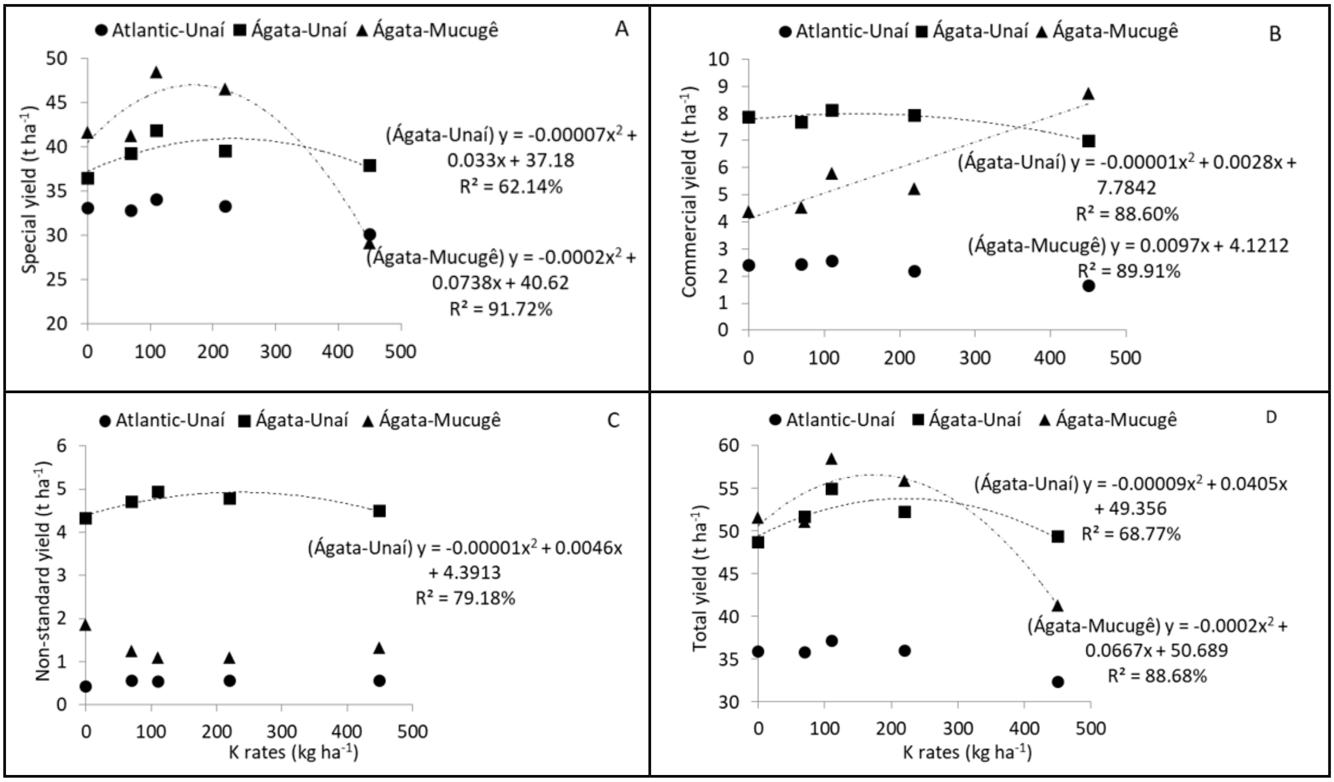

Figure 1. Yield of special class (above 45 mm) (A), commercial (greater than or equal to 33 mm and lower than 45 mm) (B) non-standard (lower than 33 mm) (C) and total (D), cultivar Atlantic and Ágata cultivated in Unaí-MG and Ágata cultivated in Mucugê-BA under potassium fertilization levels. Uberlândia, UFU, 2014.

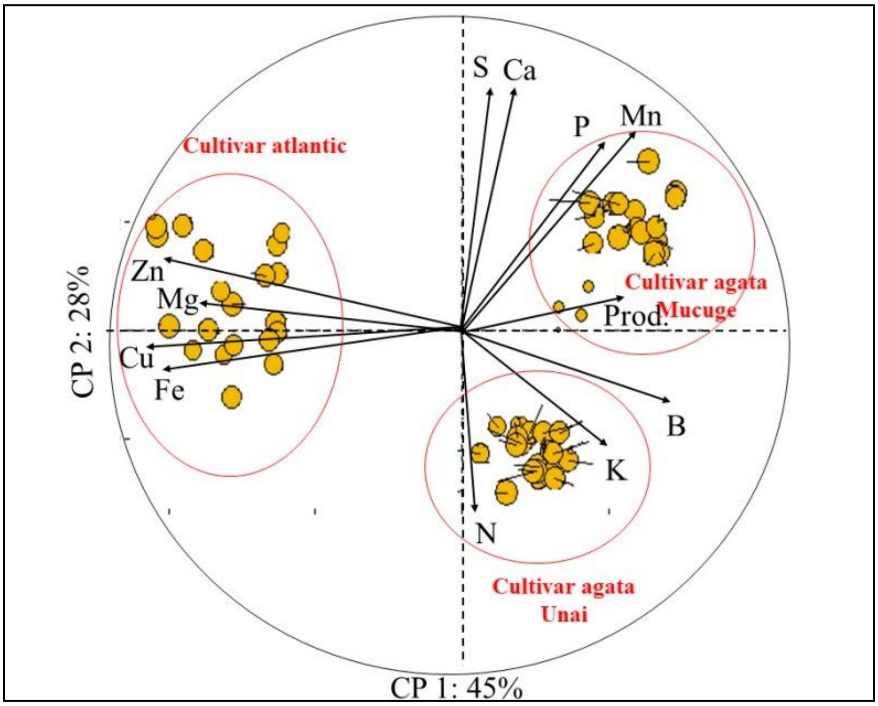

Figure 2. Principal components analysis (PCA) with the variables: macro and micronutrient contents in leaves and total yield. Uberlândia, UFU, 2014.

K_2O (7.98 t ha^{-1}) and Ágata-Mucugê, increasing productivity up to maximum dose (450 kg ha^{-1} K_2O) (Figure 1B).

For non-standard class, productivity of Atlantic-Unaí and Ágata-Mucugê ranged from 0.4 to 0.5 and 1.0 to 1.8 t ha^{-1}, respectively (Figure 1C). In Ágata-Unaí, an increase in productivity up to dose of 230 kg ha^{-1} K_2O was noticed.

The commercial and non-standard classes have low commercial value and, therefore, doses which provide more substantial increases of the special class should be chosen. At doses higher than 184 kg ha^{-1} K_2O in Ágata-Mucugê, a decrease in productivity of special class and an increase of commercial class was verified, so high doses are not necessary.

K being monovalent presents high losses by leaching in oxisols. If K fertilizer application rate is excessive, nutrient losses can occur due to leaching (Qiu *et al.*, 2014, Bhattarai & Swarnima 2016). Literature reports that 50% of applied fertilizer can be leached below 0.6 m in soil profile (Rosolem & Calonego, 2013), in a depth greater than absorption capacity by the potato root system.

Total productivity of Atlantic-Unaí ranged from 32.3 to 37 t ha^{-1}. Maximum doses estimated for total productivity in Ágata-Unaí and Ágata-Mucugê were 225 and 166.7 kg ha^{-1} K_2O, with productivity of 53.9 and 56.2 t ha^{-1}, respectively (Figure 1D).

K content in soil in the different regions studied was good (CFSEMG, 1999), indicating that the available amount for the plants was suitable. We noticed a remarkable decrease in productivity with the dose of 450 kg ha^{-1} K_2O, lower than the cropping without K fertilization yields. High K content in soil can cause misbalance in the ratios between bases (K/Ca Mg) and CTC (K/T). This condition highlights the importance of a better proportion of N, P and K in soil (Liu *et al.*, 2014).

We highlight that the rates obtained in the current studies are within the ranges recommended by CFSEMG (1999), which considered expected productivity of 30 t ha^{-1}. So far, the advances related to this rate ranges occurred due to several technological advances (irrigation management and pesticide use) and it is observed that the increase in productivity is more related to the adequate management of other factors which interfere in productivity than the use of high nutrient doses.

Singh & Lal (2012) obtained an increase of about 36% applying from 150 to 225 kg ha^{-1} K_2O, comparing with no nutrients applied. This difference found is greater than that observed in the present study, in which maximum doses obtained yields of 8.5 and 10% higher in the absence of K for Ágata-Unaí and Ágata-Mucugê, respectively. The lowest yield is related to greater-fertility soil, resulting in lower K use efficiency (Li *et al.*, 2015).

The negative impacts of high doses observed on productivity in Ágata-Unaí and Ágata-Mucugê may be more unfavorable if added to unnecessary costs and environmental impacts. Some studies highlight the influence of weather conditions of the regions and years of study on K content in soil (Zarzeck *et al.*, 2015). The technology advance has improved the understanding of the interactions which occur in soil-plant-climatic conditions of the environment.

In relation to multivariate analysis, analyzing the principal component (PCA), a formation of two-dimensional plane and two main components was noticed (PC): PC1 and PC2, representing 73% of original information. The first PC1 shows 45% of variance, followed by PC2, 28%. This result is in accordance with the criteria established by Sneath & Sokal (1973), in which the numbers of PCs used for interpretation should explain at least 70% of total variance. The data set was divided into 3 groups which were separated into Group 1: Atlantic cultivar, Group 2: Ágata-Unai cultivar, and Group 3: Ágata-Mucugê (Figure 2). This result indicated that the variables and locations showed different performances according to productivity and nutrient availability.

Cultivar Ágata-Mucugê stood out for its greater total productivities and Ca, P, S, and Mn content in leaves, with averages of 19.9; 3.9 and 1.5 g kg^{-1} and 234.4 mg kg^{-1}. When Ágata was cultivated in Unaí, highest contents of N, K and B in plants with averages of 51.5, 42.9 g kg^{-1} and 51.1 mg kg^{-1} could be noticed. Cultivar Atlantic showed the highest availability of micronutrients in soil, such as: Zn (average: 77.3 mg kg^{-1}), Cu (average: 77.2 mg kg^{-1}), and Fe (average: 284.2 mg kg^{-1}), and the highest Mg macronutrient availability, average 9.7 g kg^{-1} (Table 2).

We concluded that, to maximize K use efficiency and productivity, it is essential to observe the right dose to be used according to the response of the cultivar selected for the environment to be grown.

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